Aerosols, Lidar and IR Imaging During Duck and RED

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LONG TERM GOALS

The long-term goals of the research are to understand and assess the effects of the atmosphere on the detection of targets at low altitudes over sea in coastal regions using IR and radar systems. Effects considered are transmission losses due to aerosols and water vapor, effects of turbulent fluctuations of the air temperature on blurring and scintillation, and effects of vertical temperature and water vapor gradients on IR and rf refractivity.

OBJECTIVES

The objectives of the research performed in the framework of the present grant are to further analyze and validate results obtained in the EOPACE experiments, in particular:

– to validate the aerosol source function in the surf zone;

– to quantify the effect of the surf zone on the aerosol concentrations in the coastal atmosphere, in relation to surface-produced sea spray aerosol and anthropogenic aerosol;

– to determine the turbulence and refractivity in the inhomogeneous coastal boundary layer and their effects on imaging of low altitude point targets;

– to improve the description of the aerosol size distribution as function of height and meteorological parameters; and

– to participate in the RED (Rough Evapoaration Duct) experiments in Hawaii to:

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14. ABSTRACT
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- determine effects of scintillation and refraction in the MW IR band as function of environmental conditions through measurements with a camera mounted ashore at a range of levels above the sea surface, looking at a source mounted on FLIP;

- determine the effect of sea spray aerosol on IR propagation as function of environmental conditions, i.e. the generation of sea spray aerosol from breaking wind waves by the bubble-mediated mechanism and by direct tearing from the wave tops, the dispersal of freshly produced aerosol in the surface layer and the influence of wave induced turbulent phenomena, and the subsequent transport of the aerosol throughout the atmospheric boundary layer.

APPROACH

Data from the EOPACE IOP's (1-9) in 1996-1999 are further analyzed and interpreted. During the EOPACE experiments in Duck, North Carolina, aerosol particle size distributions were measured at three levels at the base of the pier, with the aim to derive surf-aerosol source functions and parameterize the results as function of ambient parameters. This effort is undertaken in cooperation with Prof. M. Smith from the University of Leeds (UK) who measured particle size distributions at the end of the pier. The results will be compared with those obtained at the California coast. In addition, lidar measurements were made on the aerosol plumes generated by waves breaking in the surf zone.

Furthermore, a boat was equipped with optical particle counters, a sonic, a lidar system and meteorological instrumentation to obtain data on the evolution of the aerosol size distributions and the coastal atmospheric boundary layer in off-shore winds. The goals were to study coastal aerosol transport and to validate the Coastal Aerosol Transport model (CAT) [Vignati et al., 2001], among others to determine the effects of surf-produced aerosol.

TNO-FEL prepared for and participated in the RED experiments on R/P FLIP off Oahu (HI) in August/September 2001, with aerosol and lidar experiments, and a limited set of IR propagation measurements between Oahu sites and FLIP thus covering different lines of sight. The TNO-FEL aerosol and lidar measurements were particularly focused on determination of the aerosol source function. For this reason, also an optical bubble measuring system was deployed to measure bubble spectra at about 0.5 m below the instantaneous sea surface, in combination with aerosol measurements (size distributions and profiles) between 0.5 and 10 m above the sea surface. In a cooperation with the University of Stockholm an aerosol flux system, consisting of a CPC and a sonic that was earlier used in the Arctic [Nilsson et al., 2001], was deployed from FLIP. They were complemented by simultaneous measurements of particle size distributions and, in cooperation with the University of Leeds, aerosol volatility spectra (e.g., Smith [2001]).

WORK COMPLETED

- The analysis of the surf aerosol data obtained at the California coast has been published [De Leeuw et al., 2000].

- The Coastal Aerosol Transport model (CAT) has been further developed. CAT was used for the analysis of the effects of surf-produced sea spray aerosol, such as on the total aerosol concentrations or the concentrations of HNO_3 in the marine atmospheric boundary layer. The model description and applications have been published in Vignati et al. [2001].

- The analysis of aerosol data from EOPACE IOP's has been continued in connection with the analysis of transmission measurements over Monterey bay (22 km) and San Diego Bay (7 and 15 km). The results from the analysis of IOP4 are presented in a publication submitted to Applied Optics in July 2001 [Zeisse et al., 2002]. A publication with results from other IOP's, focussing on refraction effects, is planned for submission by in FY2002 [De Jong et al., 2002].

- TNO-FEL contributed to an EOPACE overview paper that has been scheduled for publication in August 2001 issue of Opt. Eng. in [Jensen et al., 2001].

- The analysis of the Duck 1999 data has been continued. A publication on the aerosol and lidar data is scheduled for submission in FY2002.

- Several proceedings papers were produced in connection with presentations at scientific conferences (see listing in 'Publications').

- Much effort was put in the preparation for and participation in the Rough Evaporation Duct (RED) experiments off Oahu (HI) in August/September 2001, with volatility (with Univ. of Leeds, UK) and aerosol flux measurements (with Univ. of Stockholm, Sweden) as new elements.

RESULTS

The data obtained from the lidar, aerosol and turbulence measurements during the Duck 1999 experiments have been partly analyzed, see the ONR annual report for FY2000 for a brief description and some examples. A TNO report is in preparation [Moerman et al., 2001]. The analysis of the surf aerosol measurements has been postponed. Thus far, no clear relations could be derived as regards the source strength or relations with meteorological parameters, as they were observed at the California coast [De Leeuw et al., 2000]. Now that results have been made available from aerosol size distributions measured at the end of the pier [Smith, 2001], differences in concentrations at either side of the surf zone can be analyzed. On the other hand, there was no clear wind regime during Duck, and the mostly along-shore transport of the aerosols may have resulted in much better mixing than in the clear on/off-shore winds caused by the land-sea breezes encountered in California.

The coastal aerosol transport model CAT has been described in Vignati et al. [2001], together with several applications. It is currently used to evaluate the influence of sea spray aerosol produced in the surf zone in relation to effects of breaking wind waves. Recognizing that wave breaking, and thus the production of sea spray aerosol, is an intermittent process, the usually observed absence of strong vertical gradients near the sea surface can be well reproduced [Vignati and De Leeuw, 2001].

Commonly, aerosol models assume a continuous surface source. This has implications for infrared transmission close to the sea surface. The observed minima and maxima, explained to be caused by flow separation [De Leeuw, 1986; 1987] can obviously not be reproduced because wind-wave interaction is not considered in CAT. The work with CAT will be continued in FY2002. A matter of interest is that the source function derived with CAT apparently underestimates the production of the largest particles, which therefore needs to be improved.

As discussed in the FY00 report, during EOPACE experiments in 1996 and 1997 transmission was measured across San Diego Bay, along an over-water path of 15 km by TNO-FEL and over a 7 km path by Dr. Zeisse from SPAWAR Systems Center SSC (San Diego), with meteorological data collected at mid-path by Professor Davidson from NPS (Monterey). TNO-FEL also measured aerosol particle size distributions at the end of the 15 km path. The effect of the sea breeze is quite obvious due to the large influence of the surf zone on the near coastal transmission. However, the continued analysis shows that the most important effect in the IOP4 data set is refraction, leading to very large variations in the transmission values. The effects of refraction were further analyzed by SSC as described in Zeisse et al. [2002]. Further efforts were made at TNO-FEL to understand the effects of refractivity, by using the IRBLEM model. In parallel, and as part of other projects, the TNO-FEL micro-meteorological model was extended with ray tracing and other modules. The extended model (RTEAM) will be used in the further analysis of EOPACE, RED and other data sets. The analysis of other EOPACE propagation data is focussed on various refraction phenomena observed, through a number of selected case studies.

In a cooperation with Prof. Smith (Univ. of Leeds) and Dr. Gathman (Science and Technology Corporation, San Diego, CA) aerosols measured during the EOPACE IOP4 and IOP7 at Naval Amphibious Base (NAB) and Imperial beach Pier (IBP) are analyzed to determine the impact of surf aerosols and urban pollution upon visibility and IR transmission in a coastal region. Results will be published in a refereed journal.

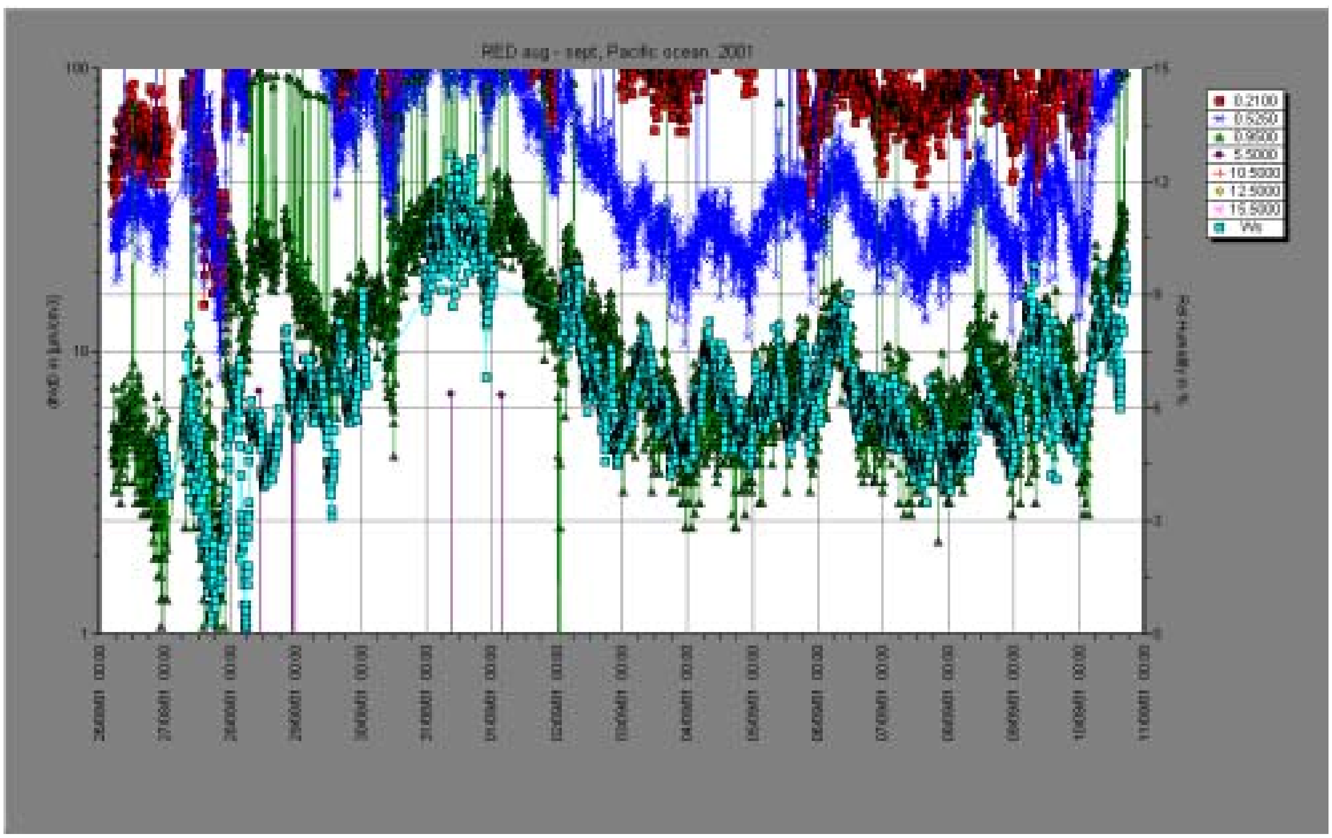

Figure 1. Time series of aerosol concentrations with diameters of 0.21, 0.52 and 5.5 μm, and wind speed, measured aboard R/P FLIP during RED in the period Aug. 26-Sept. 11 (preliminary data).

At the time of writing of this annual progress report, the RED experiments are being terminated. Some initial data evaluation has been undertaken as a quality check on the different kinds of data obtained. An example is shown in Figure 1, of time series of aerosol concentrations dN/dD (μm^{-1} cm^{-3}) for particles with diameters of 0.21, 0.53 and 5.5 µm, together with wind speed, for the period August 26 until September 11, 2001. Note that these are preliminary data that have not yet been validated. Wind speeds up to about 12 ms^{-1} were encountered and in general the aerosol concentrations trace the wind speed very well, except for, e.g., 28-30 August. The general impression from the RED experiments was that aerosol concentrations were very low, the occurrence of whitecaps was smaller than hoped for. Very few lidar scans could be made during the time when safety allowed for it use (i.e., no airplane or boat operations in the area). An example of a vertical scan is presented in Figure 2.

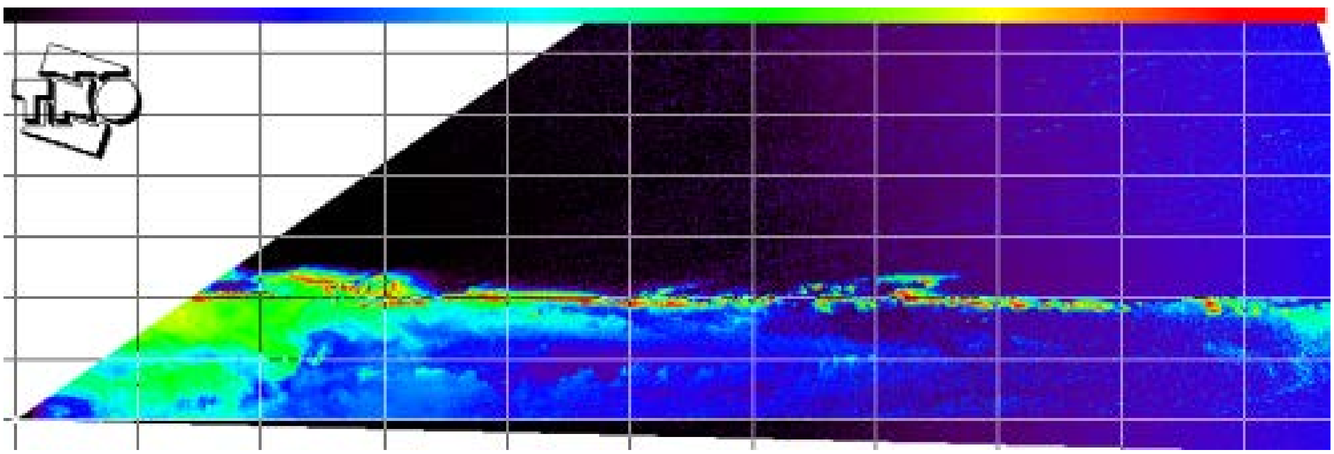

Figure 2. Vertical lidar scan during RED, showing the BL height and convective structure.

IMPACT

The results can be used to assess the effects of the atmosphere on the performance of thermal imagers over sea, and in particular the performance of LR-IRST systems. The surf-produced aerosol affects atmospheric processes involving sea spray particles, such as heterogeneous reactions, at fetches of at least 10 km in off-shore winds. Reaction between sea spray and HNO_3 has consequences for atmospheric inputs of nitrogen compounds in coastal waters, and thus eutrophication [De Leeuw et al., 2001; Sorensen et al., 2001]. Over land, sea spray influences fragile coastal eco-systems, and the corrosive properties cause damage to buildings, structures and cultural heritage.

TRANSITIONS

The EOPACE results of TNO-FEL are exchanged with other EOPACE and RED participants, for common analysis combining all required expertise to achieve the EOPACE and RED goals. Common EOPACE publications have been published, others are submitted or in preparation.

RELATED PROJECTS

The efforts described above are in conjunction with other projects addressing electro-optical propagation over sea, in part basic research, in part applied research. The EOPACE efforts take place in conjunction with EOPACE studies funded by the Netherlands Ministry of Defense, including work on long-range transmission, IRST and backgrounds. Data from other areas, e.g. the North Sea, the North Atlantic, the Mediterranean and the Baltic, are from other projects supported by the Netherlands Ministry of Defense, the EU or other funding agencies.

SUMMARY

New knowledge has been acquired on the effect of the surf zone on aerosol concentrations in the coastal zone. Explanations for the lack of vertical variation of the concentrations of sea salt produced at the sea surface from breaking waves are provided from model simulations. Observed effects of refractivity on propagation over the coastal ocean seas have been explained with models. New data have been collected near Oahu (HI), from which it is hoped to derive direct information on the aerosol transported from or to the sea surface.

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